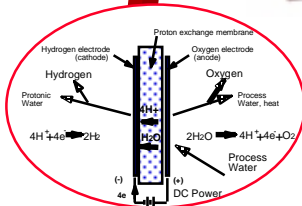
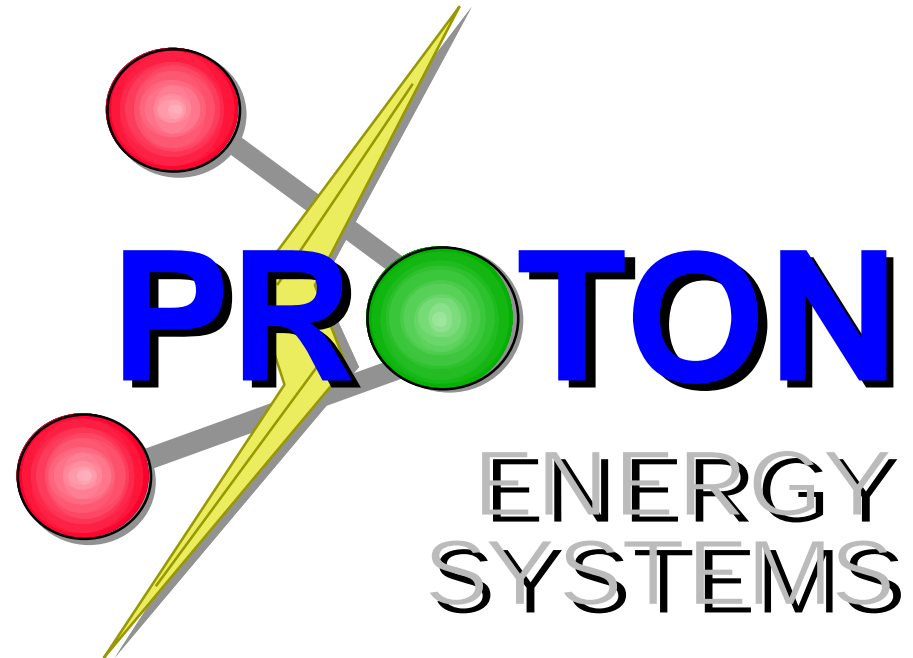
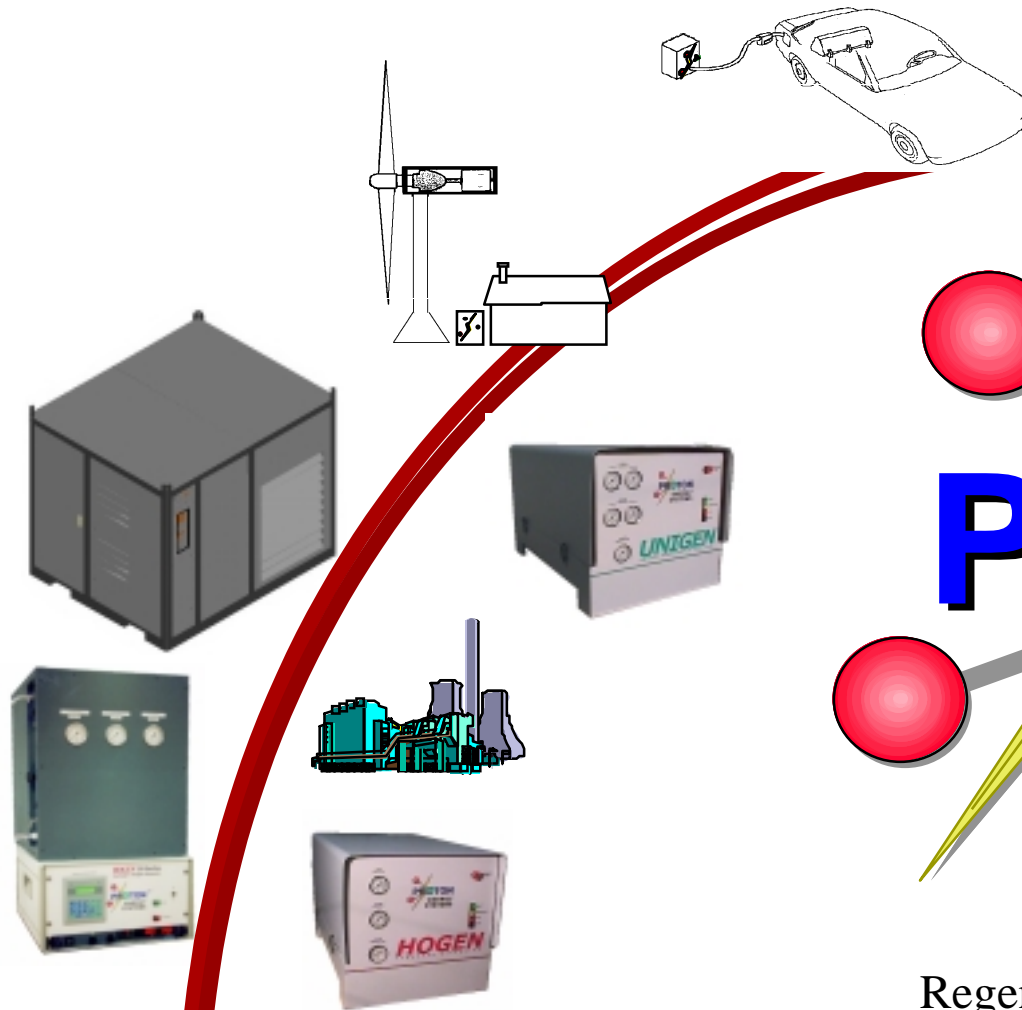
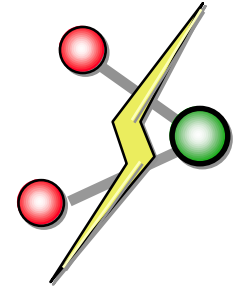


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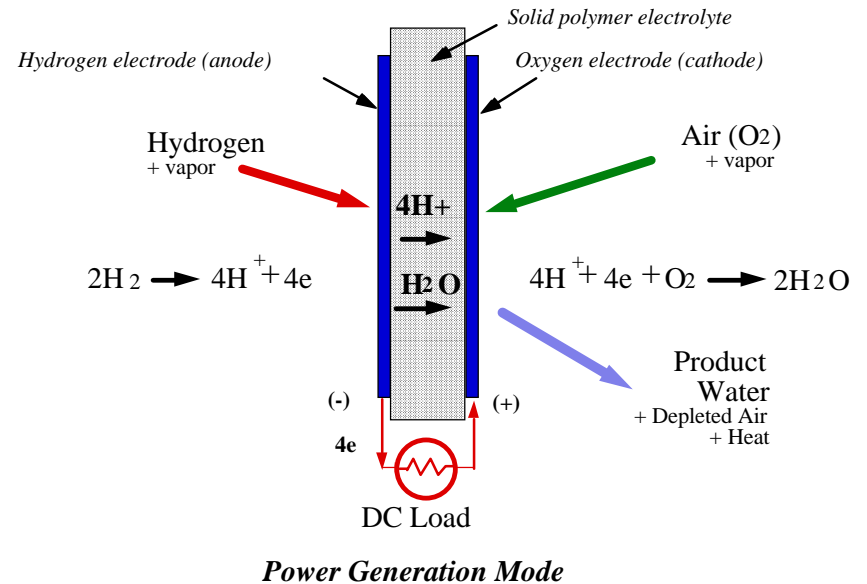
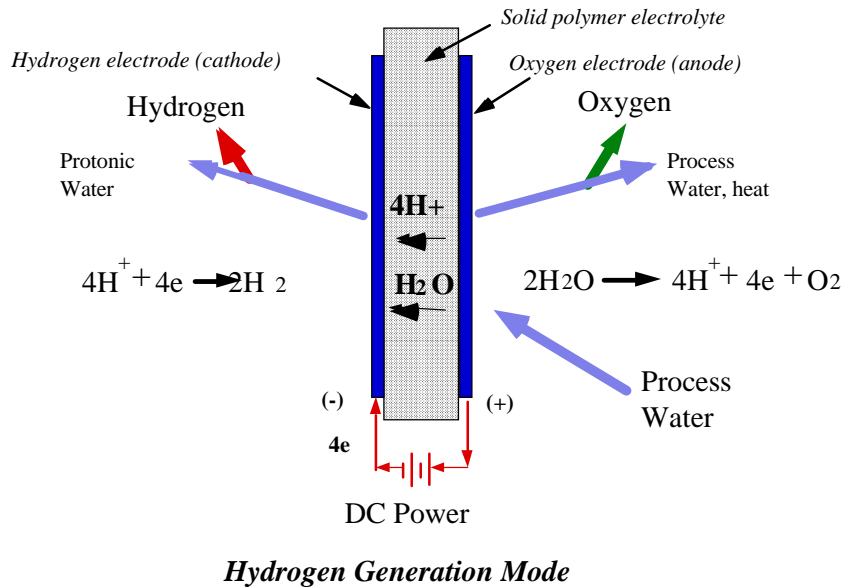
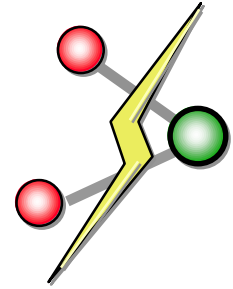
Regenerative Fuel Cell  
Technology and Applications  
BY  
**TRENT M. MOLTER**  
VICE PRESIDENT  
TECHNOLOGY & PROCESS DEVELOPMENT

# Agenda

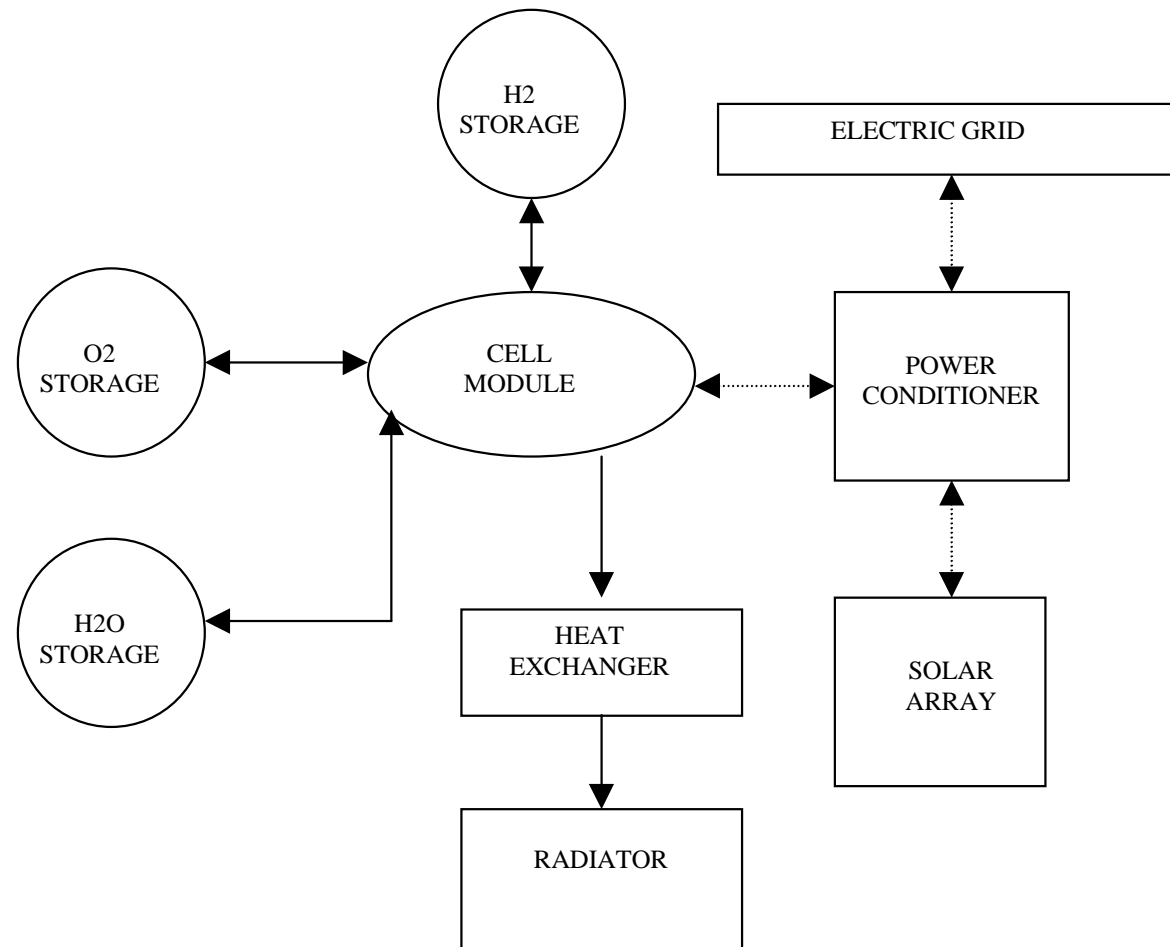
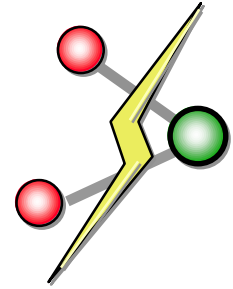


- **Introduction to a Regenerative Fuel Cell**
- **Key Technical Issues**
- **System Design**
- **System Testing**
- **Product Attributes**
- **Market Scope and Drivers**
- **Future Development Needs**
- **Summary**

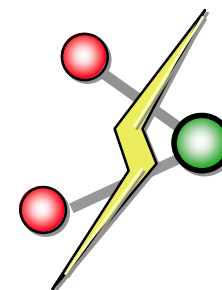
# Regenerative Fuel Cell Electrochemistry



# Regenerative Fuel Cell System Block Diagram



# Field Experience Further Supports System Design Efforts



Microelectronics Fab



Energy Storage

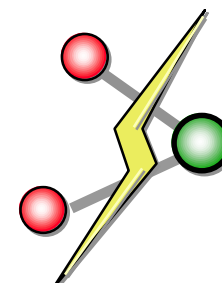


Fuel Cell Research

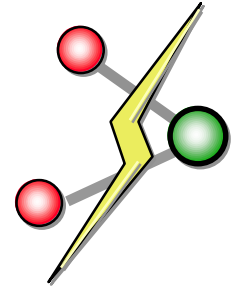


Merchant Gas

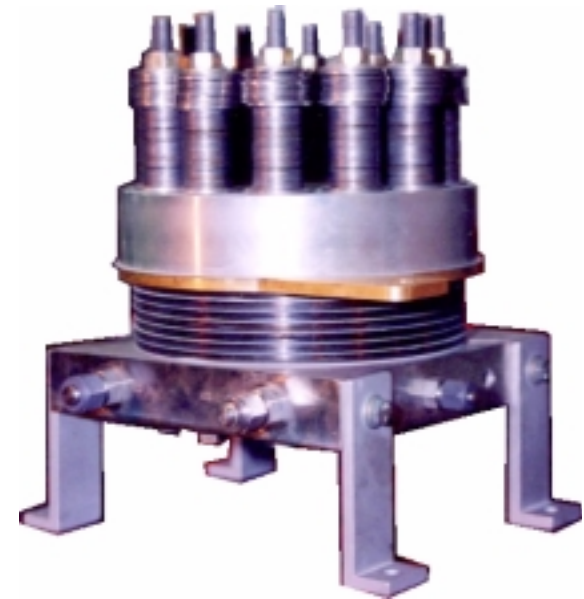
# High Pressure PEM Electrolysis Provides the Design Basis for URFC's



# Key Technology Challenges

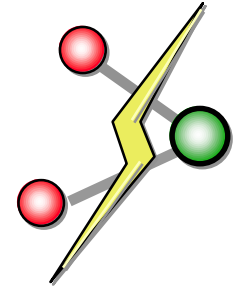


- **Reversible Cell Structure**
  - Fuel Cell/Electrolysis Transition
  - Reversible Oxygen Electrode
  - Materials Challenges
- **High Pressure Gas**
  - Cell Structure
  - Oxygen/Hydrogen Safety
- **Difficult System Integration**
  - Multifunction Process
  - Control Requirements

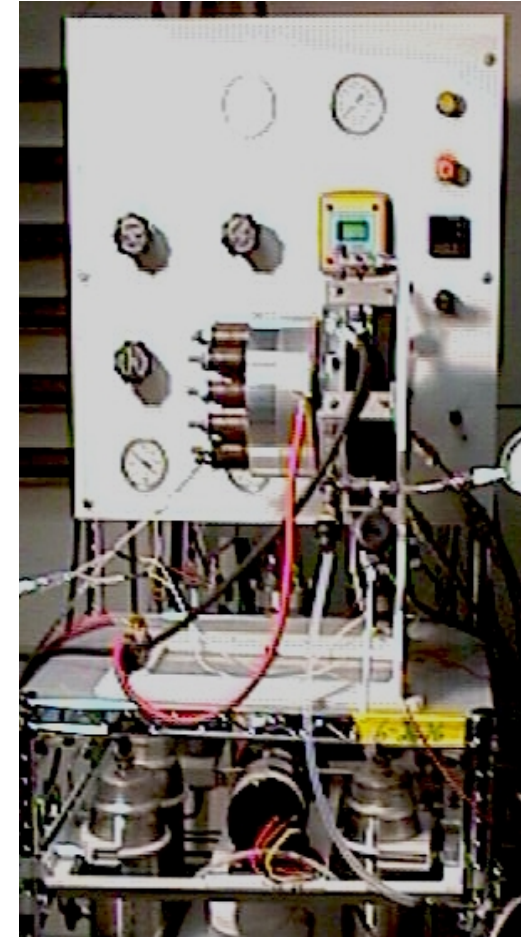




# Design Strategy

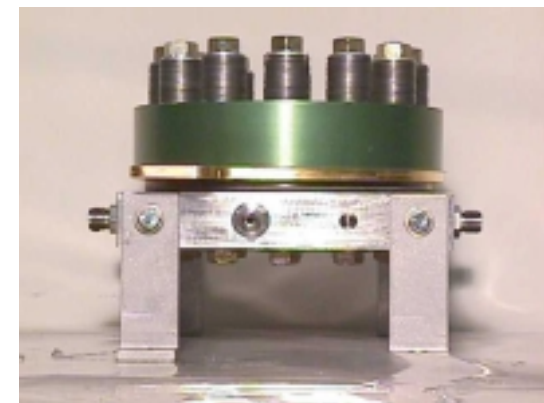
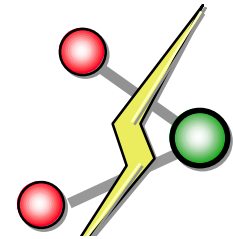


- **PROTON's Proprietary Electrolyzer Cell and System Configurations Serve as Design Basis**
- **Cell Design Modified to Include Features Necessary for Fuel Cell Operation**
- **System Electrolysis Fluids Process and Control Loop Modified to Incorporate Provision for Gas/Water Reversal**
- **Design Process Supported With Laboratory Test System**



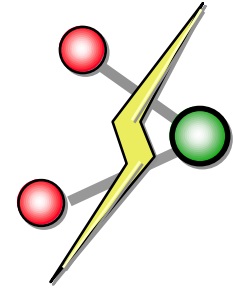


# EPRI Sponsored URFC Demonstrator

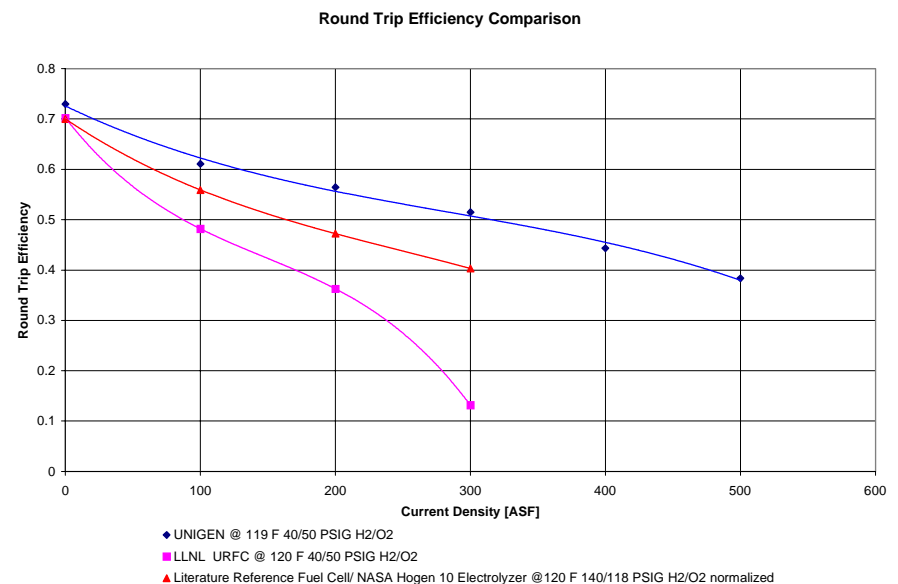


250 Watts  
200 Watt - Hours  
Fully Automated  
0.1 Ft<sup>2</sup> Active Area Cell Design  
150 PSI Capable

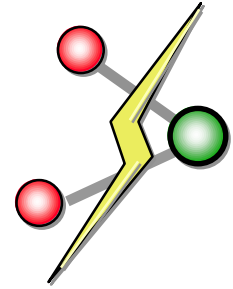
# URFC's Can Offer a 40 - 50% Electric to Electric Round Trip Efficiency



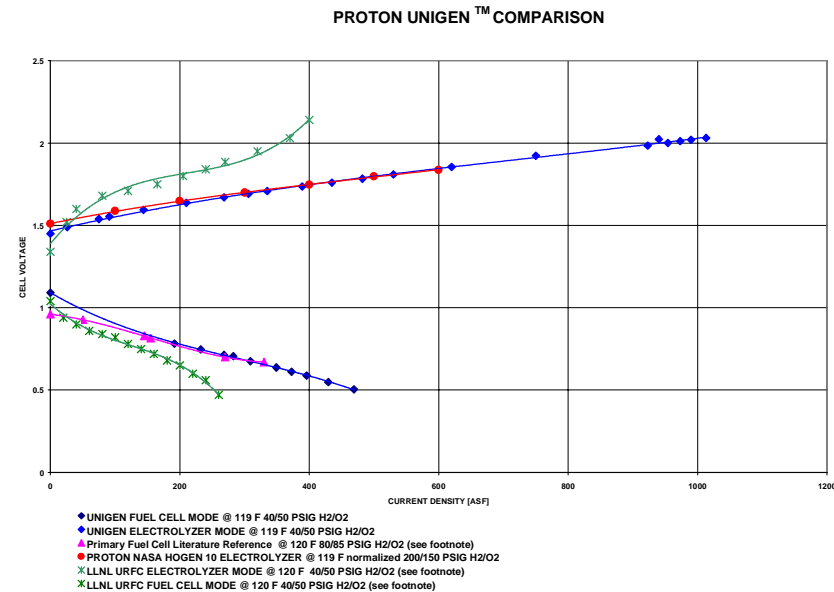
- **Round Trip Efficiency Depends Heavily On Duty Cycle**
- **Other Factors Must Be Considered**
  - Power Conditioning Losses
  - System Parasitics
  - Gas Storage Efficiencies
  - Useful Heat Recovery



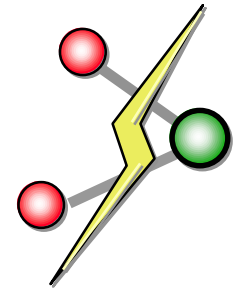
# Moderate Pressure Testing Shows Comparable Performance to Dedicated Systems



- Nafion 117, 0.1 Ft<sup>2</sup> Active Area Cells
- 120 F, 40 - 50 PSIG Gases
- >150 Round Trip Cycles
- > 300 Hours of Operation

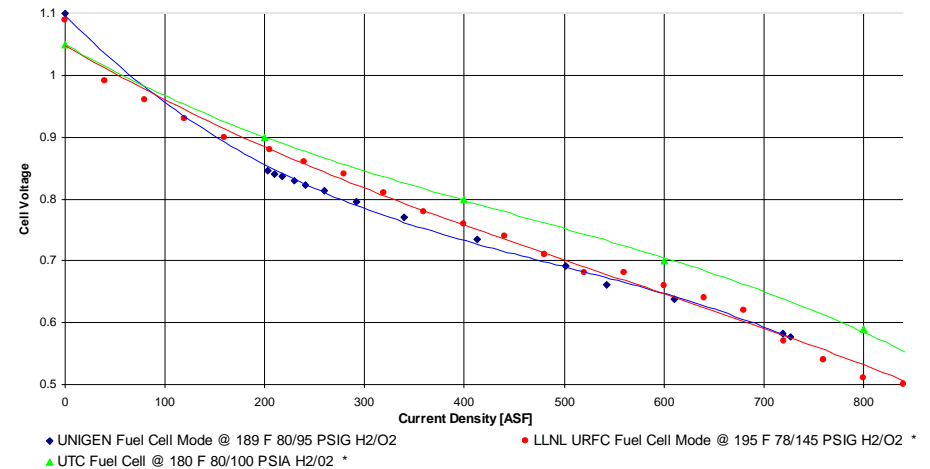


# Higher Pressure Fuel Cell Performance

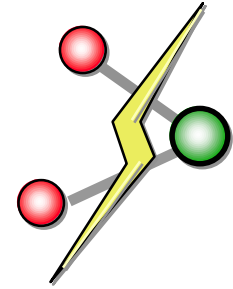


- Much Higher Voltage Performance
- URFC's Deviate Slightly From Dedicated Fuel Cell Performance

UNIGEN™ Performance Comparison

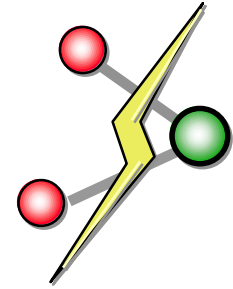


# URFC's Can Compete With Diesel Generating Sets in Many Instances



	<b>Diesel Genset</b>	<b>URFC</b>
Reliability	Med	High
Maintenance	Refurb Needed After 3-5000 Hours	40,000 + Hours Before Stack Maintenance
Noise	Noisy	Quiet
Efficiency	30% Typical	30-50% Possible
Fuel Issues	Fuel Can Contaminate Groundwater	H2 Clean & Dissipates Immediately
Load Following	Poor Idle Will Consume Fuel	Direct & Instantaneous

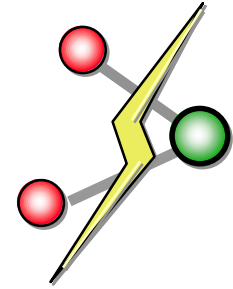
# URFC's Provide a Lower Cost Energy Storage Alternative Over Batteries in Many Instances



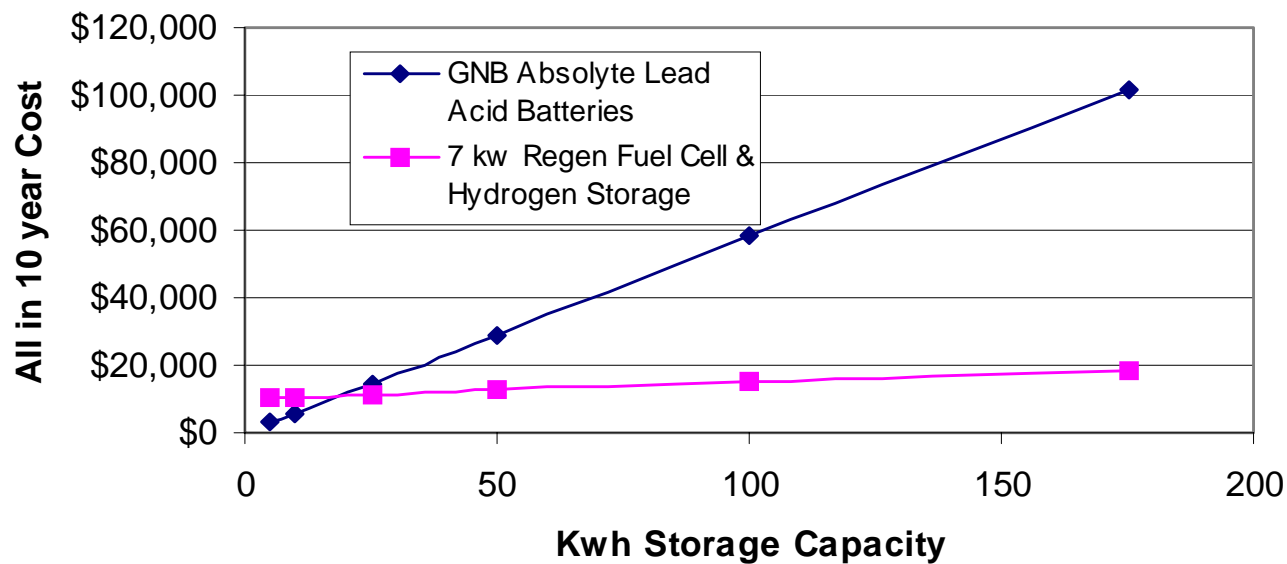
	<b>Batteries</b>	<b>URFC</b>
Life Cost 200kwh System	\$120,000	\$20,000
Incremental Additional Storage Life Cycle Cost	\$150-300/Kwh	\$30/Kwh
Calendar Life	5-8 Yr.	System: 20 Yrs With Maintenance
Cycle Life	6400 @ 10% DoD 800 @ 100% DoD	20,000+ Cycles @ 100% DoD
Maintenance Required	Complete Battery Replacement After Cycle Life Or Calendar Life Limit Reached	Cell Stack Only Refurb After 60,000 Hours
Environmental Operating Hazard	Batteries Need Indoor Storage, Acid Present	H2 Stored Outside System Can Be Either Indoor Or Outdoor
Disposal Hazard	Lead, Acid Issues	None : Discharged System Has No Hazardous Materials



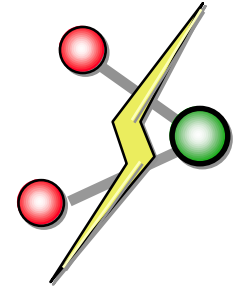
# Energy Storage System Cost Comparison



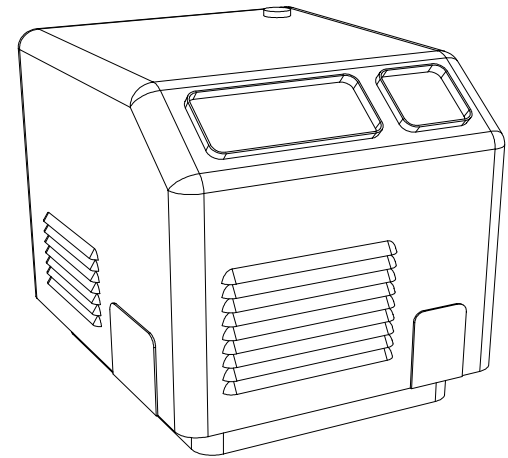
**10 Year Energy Storage System Cost Comparison:  
Lead Acid Batteries vs. Proton Regen Fuel Cell &  
Hydrogen**



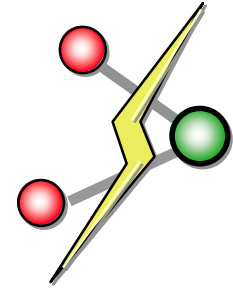
# Market Challenges



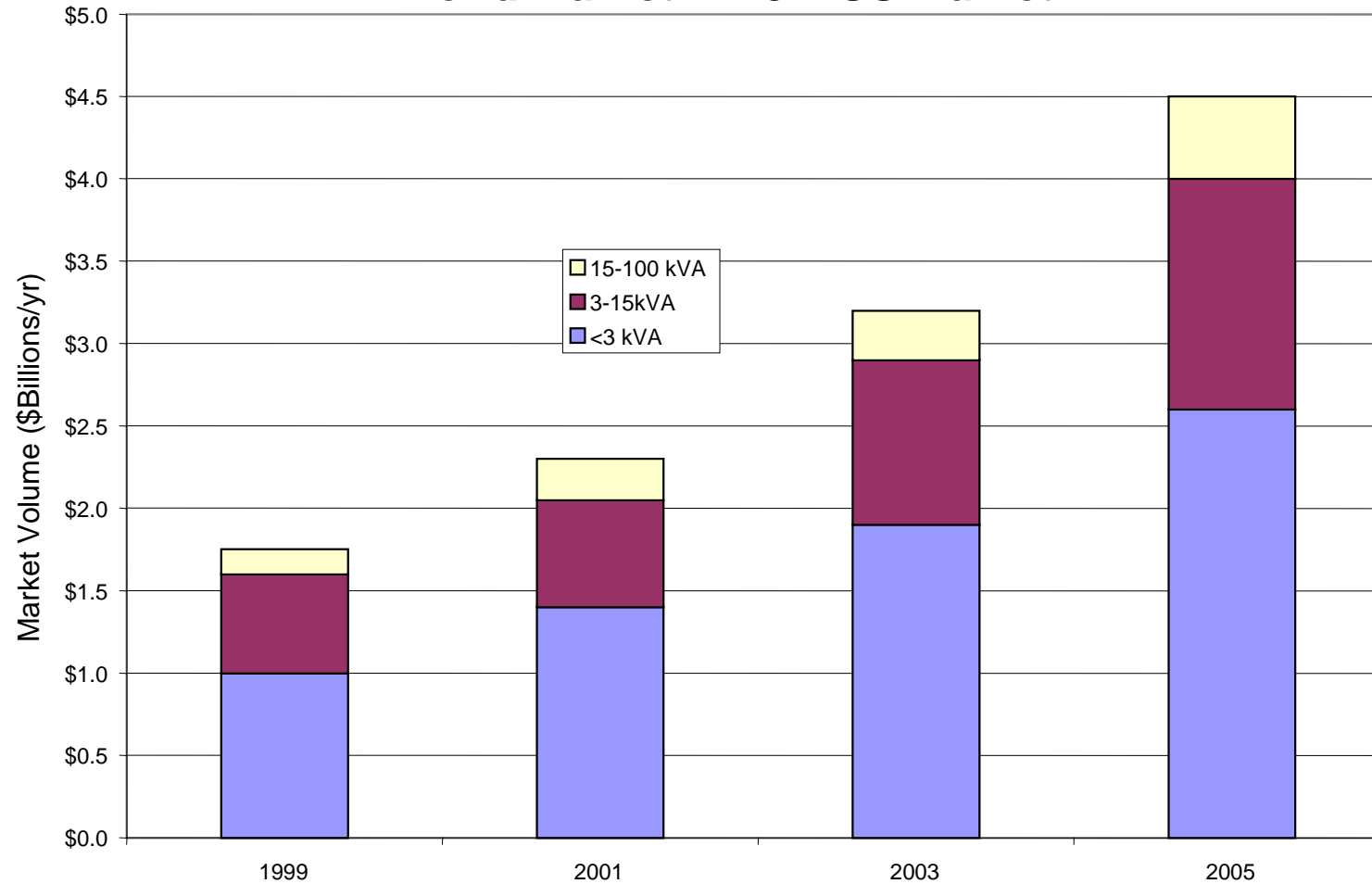
- **New Mode of Energy Storage & Power Delivery**
- **Perceived Technology Risk**
- **Entry Level Cost**
- **Acceptance of Hydrogen Storage**
- **Integration into Existing Applications**



# UPS Systems: US Market

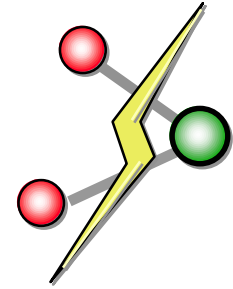


**US Annual Market Volume for UPS Systems <100 kVA**  
**World Market = 2.3 x US Market**



Source: Technology Insights/Frost & Sullivan - Year

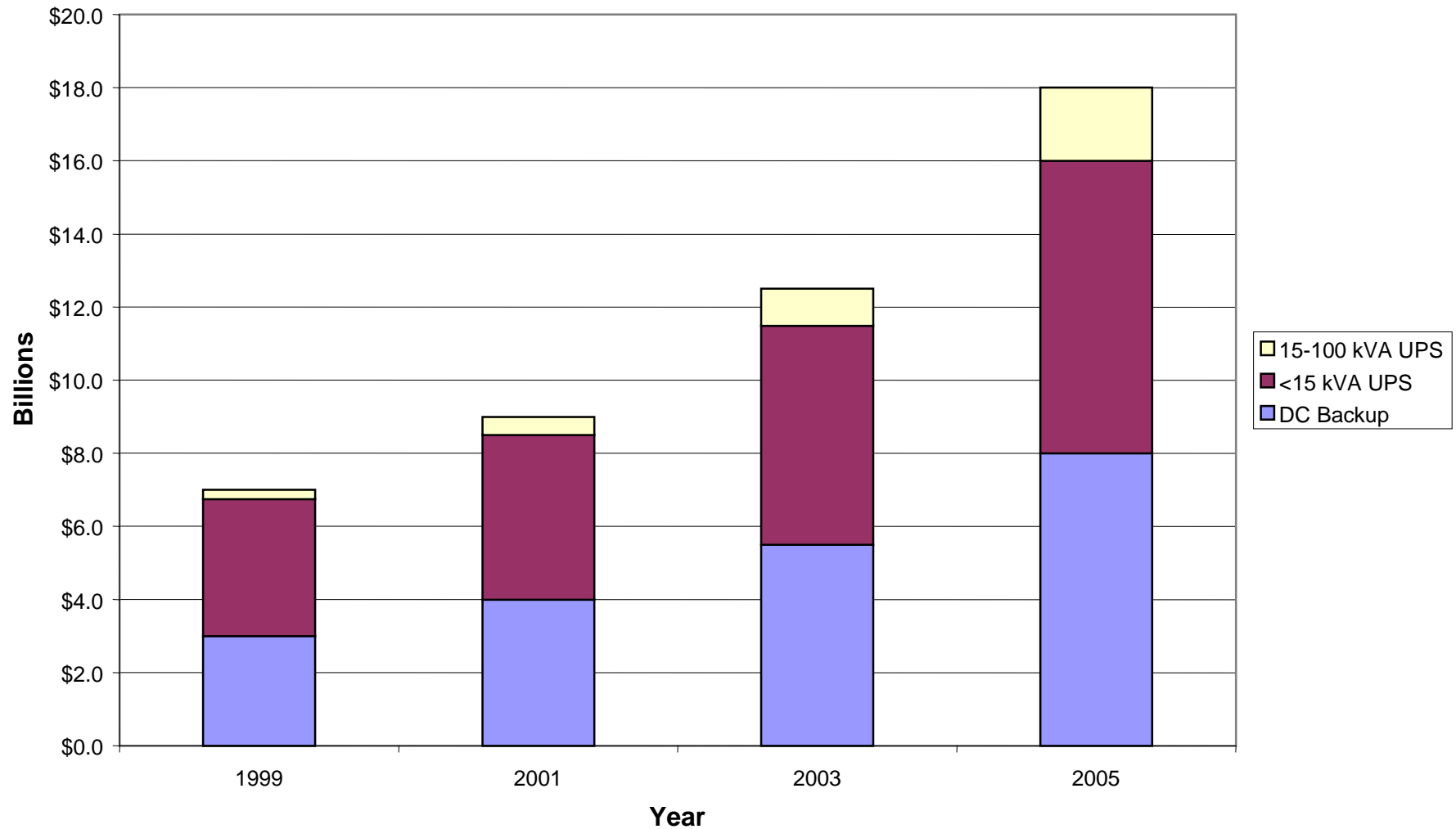
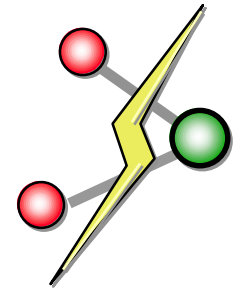
# Future Development Needs



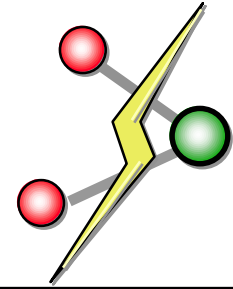
- **Parametric and Life Testing of Advanced Configurations**
- **Scale-up to 1 - 10 kW Range**
- **Establishment of Product Requirements With End Users**
- **Initiation of Product Development Efforts**



# Global Backup Power Market



# Summary



- **Key Technical Challenges Relative to Regenerative Fuel Cells Have Recently Been Addressed**
  - Reversible Cell Structure
  - High Pressure Gas Generation
  - System Integration
- **Technology Demonstrated in a 250 W Laboratory Scale System**
- **Multi-Billion Dollar Markets Exist for Battery and Diesel Generator Replacement**
- **Product Development Efforts are a Logical Next Step**
  - Advanced System Component Testing
  - Scale-up to 1-10 kW